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THE SUN'S ATMOSPHERE:

A REVIEW OF BIGELOW'S WORK ON THE SUN

By ELLSWORTH HUNTINGTON

Professor Frank H. Bigelow, lately of the U. S. Weather Bureau and now of the Argentine Meteorological Office, has recently published "A Treatise on the Sun's Radiation"[1] which is a continuation of his "A Meteorological Treatise on the Circulation and Radiation in the Atmospheres of the Earth and of the Sun,"[2] published in 1915. Both books are alike in being full of the stiffest kind of mathematics and hence in being not only incomprehensible but unreadable by the average scientist. Both are also alike, however, in being of high importance as pioneer volumes in the complete reconstruction of meteorology and solar physics which is fast acquiring momentum. The reviewer makes no pretense of being able to judge the mathematical merits of Bigelow's last book, or even of having understood a large part of it, for such an understanding is possible only to a few highly trained mathematicians. Nevertheless, he feels safe in making two statements. The first is that future work will reveal many errors. Where so many assumptions are required and so many diverse methods of calculation are available, it is humanly impossible for a pioneer worker to be entirely correct. Critics of far less ability and originality than Professor Bigelow are sure to magnify these errors, overlooking the truth which the reviewer believes to be embodied in his second statement, which follows.

IMPORTANCE OF BIGELOW'S WORK

The second statement is that Professor Bigelow's main conclusions are probably for the most part correct, and even where they are in error they take high scientific rank because of their originality and because of their stimulus to other workers. There are two main reasons why the reviewer, in spite of his inability to follow the intricate mathematical processes, believes that this statement is warranted. The first is that the author has "made good." Twenty or thirty years ago he advanced a number of new ideas which were received in some quarters almost with derision. They dealt with such matters as the shifting of storm tracks in response to solar changes, the relation of storms to magnetic disturbances, and the general relation of atmospheric circulation to solar variations. These ideas made many people regard Bigelow as "visionary," but time has vindicated him. All his main ideas, with such modifications as new work, of course, must bring, are now accepted by a large and growing body of the leading students of meteorology. In line with this progress the U. S. Weather Bureau is now experimenting with the use of solar observations in order to help in predicting the weather. The Bureau will probably have only indifferent success until the importance of electrical as well as thermal conditions is recognized, but the fact that the importance of solar variations is thus admitted is a tribute both to Bigelow and to the progressiveness of the Weather Bureau.

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[1] F. H. Bigelow: A Treatise on the Sun's Radiation and Other Solar Phenomena, in Continuation of the Meteorological Treatise on Atmospheric Circulation and Radiation, 1915. ix and 385 pp.; diagrs., index. John Wiley & Sons, Inc., New York; Chapman & Hall, Ltd., London, 1918. $5.00. 9 x 6.

[2] Reviewed in the *Geogr. Rev.*, Vol. 2, 1916, pp. 323-324.

The second reason for thinking that Bigelow is on the right track is that the results give unity and scientific coherence to a subject which has hitherto been extremely vague. Moreover, by means of his methods, observations which had previously seemed discrepant now fall into harmony.

THE CONSTITUTION OF THE SUN: THE ISOTHERMAL LAYER OF ITS ATMOSPHERE

The book under review treats the sun's atmosphere exactly as the earth's atmosphere is treated in a previous book. We must think of the sun, the author tells us, as a central mass of semi-solid gases under inconceivably great pressure and at temperatures which can only be guessed. From this central mass outward there is a gradual decline in pressure and temperature according to the well-known laws of adiabatic cooling, which have been thoroughly worked out in the earth's atmosphere. Finally, on the sun, just as on the earth, an isothermal layer is reached where for an appreciable radial distance there is no change of temperature. In this layer several important alterations take place. First, many or perhaps all of the elements are transformed from the atomic to the molecular condition. The heat given out by this transformation is apparently the reason why the solar atmosphere does not change in temperature. Again, the heavier gases, such as those of the metallic elements, here reach their highest level. An occasional jet of iron or mercury or some other heavy element may be carried up in a vortical whirl, but only rarely and to a short distance, for its weight causes it to fall back at once. The presence of the isothermal layer and the fact that the heavy elements rise no higher explain a condition which has puzzled a great many students, namely the sharpness of the sun's rim. According to the old ideas the gaseous condition of the sun ought to give a hazy rim corresponding to a gradual decrease in the density of the gases. Bigelow's hypothesis gives an edge which would appear sharp from the earth. Outside of the isothermal layer the sun's atmosphere cools more rapidly than below, for the process becomes non-adiabatic.

BEARING OF EXTREME COMPLEXITY OF SOLAR PHENOMENA ON OUR KNOWLEDGE OF THE RELATIONSHIP BETWEEN THE SUN AND THE EARTH

The conception of an isothermal layer leads to an explanation of sun spots, faculae, flocculi, and prominences. Each is due to some special method by which the gases below the isothermal layer break through and are shot outward and then grow cool and fall back. For the ordinary worker the great lesson of this part of the book is the extreme complexity of the solar phenomena and the probability that a vast number of changes occur in such a way that they cannot be detected from the earth except by the use of new methods. The most hopeful method for such detection lies in further study of electrical, magnetic, and perhaps radioactive conditions, but even these may not reveal all the sun's activities. Hence if a connection between sun spots and weather is established, as has been done again and again, the chances are that the real connection is far greater than appears on the face of the returns, for an unknown number of other unmeasured solar conditions are also changing. The true relationship between the sun and the earth can be determined only by combining all of these solar phenomena on the one hand and all the changes in the earth's atmosphere on the other.

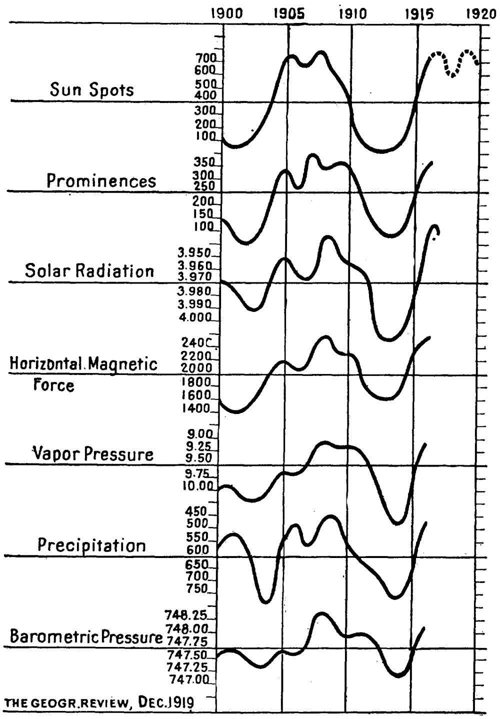

FIG. 1—Diagram showing the synchronism of the solar and terrestrial variations (reproduced from Fig. 27 of F. H. Bigelow's "A Treatise on the Sun's Radiation," 1918).

NEED OF CO-ORDINATION OF SOLAR AND TERRESTRIAL DATA

In this connection Bigelow points out[3] that the "growth of research is unduly retarded" because the solar and terrestrial data are

> not sufficiently homogeneous to bring out clearly the small true solar residuals; the observations are made in the interests of short-range forecasts to the entire neglect of the long-range forecasts of solar physics; the several branches of the subject are so scattered as to be unmanageable—the solar physics, the bolometric spectra, the magnetic field, the electric ionization, the climatic meteorology, all being separated among different administrative offices; the published reports from these different sources are so retarded that they are useless in any study of current forecasts whatsoever; there exists no systematic machinery for handling this kind of world-wide material.
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> It is inevitable that several international institutes shall be established—*at least four,* one in the United States, one in Argentina, one in Europe or Asia, and one in Africa or

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[3] P. 237.

> Australia—which shall co-operate upon a fixed general plan, utilize selected data, and treat the subject from the world-wide point of view. The long-range system [of forecasting which Bigelow believes to be now practicable] will begin with annual forecasts, already easy in Argentina, and advance to details [as to months, weeks, and days] in accordance with the progress in solar physics.

Whatever his views may be, no student of meteorology, climatology, magnetism, or solar physics, will question the value of such institutes. From the purely financial standpoint they would in a few decades prove great money-makers, not for themselves, but for mankind.

AGREEMENT BETWEEN SOLAR AND TERRESTRIAL PHENOMENA

Turning now to the point which gives chief interest to all solar studies, namely their relation to the earth, Bigelow does not take this up so fully as might be wished. In fact the greatest lack of the book is actual facts as opposed to theoretical deductions. On page 234, however, the author gives a set of tables which are so valuable that they are here reproduced, together with the corresponding diagram. A marked agreement between solar and terrestrial phenomena is evident both in the 11-year cycle and in a shorter cycle which Bigelow calls 3.75 years.

SUMMARY OF THE SOLAR AND TERRESTRIAL OBSERVATIONS SHOWING A SYNCHRONISM IN THE VARIATIONS IN THE 11-YEAR AND THE 3.75-YEAR PERIODS

YEAR OF OBSERVATION	SUN SPOTS	PROMINENCES	RADIATIONS	HORIZONTAL MAGNETIC AMPLITUDES	PRECIPITATION	TEMPERATURE	VAPOR PRESSURE	BAROMETRIC PRESSURE
1900	114	128	.....	1,589	855	17.81	10.50	749.28
1901	33	88	.....	1,374	573	17.87	9.88	49.43
1902	60	47	.....	1,464	716	17.68	10.35	48.59
1903	293	118	3.989	1,926	775	17.49	10.52	49.22
1904	503	291	3.979	1,787	914	17.17	10.30	49.12
1905	762	302	3.955	2,194	719	16.75	10.22	49.24
1906	646	261	3.975	2,015	613	17.55	10.07	49.33
1907	745	427	3.971	2,299	648	16.83	9.86	49.52
1908	583	346	3.940	2,584	615	17.11	9.55	49.97
1909	527	365	3.960	2,334	566	17.08	9.34	49.90
1910	223	259	3.952	2,354	651	16.96	9.31	49.59
1911	68	163	3.960	1,923	751	16.40	9.26	49.75
1912	43	126	3.978	1,520	811	17.51	10.09	49.72
1913	17	135	4.003	1,564	704	18.19	10.53	49.44
1914	115	198	4.002	1,672	928	17.28	10.78	48.77
1915	350	250	3.990	2,635	773	17.32	10.06	48.92
1916	540	400	3.920	2,676	486	17.65	8.87	49.00

Sun spots.—Data from Wolfer's frequency numbers, *Meteorol. Zeitschr.*, May, 1902; May, 1915.

Prominences.—Data from Ricco's Distribuzione delle protuberanze, *Memorie Soc. degli Spettroscopisti Italiani*, March, 1914.

Radiation.—Bigelow's reduction of the pyrheliometer data.

Horizontal Magnetic Amplitudes.—Bigelow's compilation from European observatories and Pilar, Argentina.

Precipitation, Temperature, Vapor Pressure, and Barometric Pressure.—From the Argentine stations Tucumán, Andalgala, Goya, Concordia, Córdoba, Pilar, Buenos Aires, Victorica, Bahia Blanca, Patagones.

VALUE OF THE SOLAR CONSTANT

One other point deserves notice. Bigelow disagrees radically with Abbot as to the value of the solar constant. He holds that in his calculations Abbot has omitted important factors, such as potential and electromagnetic energy, which ought to be considered as well as kinetic energy. The question is so purely mathematical that the reviewer cannot judge its merits; but Bigelow's results seem to be the more consistent. He concludes that the temperature at the sun's isothermal layer is 7,655° C. This gives a solar constant of 5.85 gram calories per centimeter per minute, but in passing through the rest of the sun's atmosphere this is diminished to 3.98. Bigelow seems to state that the difference in brightness between the sun's center and edge is equal to the diminution which the sun's energy suffers in passing out from the sun into space, that is $5.85-3.98=1.87$; but it is impossible to tell how he arrives at this conclusion. The value 3.98 is held to be the amount of energy received at the upper limit of the earth's atmosphere, a value which Abbot puts at only 1.93, or half as much. The difference between these two views is of great practical importance because the greater the energy received from the sun, the greater the intensity of changes, and the greater the likelihood that the breaking forth of the hot lower solar gases through the isothermal layer may cause pronounced climatic fluctuations upon the earth.